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ECONOMICS OF WIND ENERGY FOR IRRIGATION PUMPING

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ECONOMICS OF WIND ENERGY FOR
IRRIGATION PUMPING

by

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Technical Completion Report

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EXECUTIVE SUMMARY

How much can an irrigator afford to invest in a wind turbine system for pumping irrigation water? This study addresses some of the economic questions associated with wind power as an energy source for irrigation under different situations in seven regions of the nation. The analysis will provide the United States Departments of Energy and Agriculture with target investment costs for wind turbines used for irrigation pumping; it also will provide policy makers with bases for adjusting taxes to make alternative sources of energy investments more attractive.

Three types of wind systems were considered for each of the seven regions. These regions were selected on the basis of the typical wind power available during the irrigation season and other factors, such as the length of the irrigation season and the quantity of irrigation water required. The regions were:

- A. Kansas, Oklahoma, High Plains of Texas, High Plains of New Mexico, and Eastern Colorado.
- B. Nebraska, South Dakota and North Dakota.
- C. South Texas (Edwards Plateau) and Pecos Valley of New Mexico.
- D. Southern Arizona and Southern California (primarily the Imperial Valley).
- E. Snake and Columbia River Basins in Idaho, Oregon, and Washington.
- F. Midwestern U.S. -- Illinois and Indiana.
- G. Southeastern U.S. -- Florida and Georgia.

The three types of wind powered irrigation systems evaluated for each region were: wind assist combustion engines (diesel, natural gas, propane pane), wind assist electric engines, with or without sale of surplus electricity, and stand alone reservoir systems with gravity flow reservoirs.

The wind assist units essentially consist of vertical axis turbines connected to a conventional power source by means of an override clutch. Conventional fuel consumption would be reduced when wind power is used, but

the system would retain its ability to function without wind power, if necessary.

With the stand alone system, water would be pumped directly by wind into a reservoir for use when irrigation water was needed. Outflow from the reservoir would be by gravity.

The approach used in the study of wind assist systems was as follows: (1) estimates were made of the average monthly amount of energy that can be harvested by a wind turbine under average conditions; (2) estimates were made of the economic value of the energy saved and/or sold; and (3) assessments were made of what irrigators in selected situations could afford to pay for wind turbines of different sizes. A similar approach was used for analyzing stand alone systems, with two additional steps: various combinations of reservoir and turbine sizes necessary to meet water demands were calculated for selected situations, and reservoir construction costs were estimated.

The amount that one could afford to invest in wind turbines was estimated for average conditions in each wind region, under three energy price projections, for each major energy source, over a 20-year period. Discount rates of 7 and 10 percent were used in these analyses.

Energy Savings

The estimated amount of energy saved from assisting conventionally powered irrigation pumping units with wind turbines ranged from 13 kilowatt hours per square meter of turbine size (kWh/m^2) in Region F to 117 kWh/m^2 in Region D. When the electricity that could be generated during non-irrigation periods was added to irrigation savings, total estimated energy saved ranged from 565 kWh/m^2 for Region A to 93 kWh/m^2 for Region G.

Economic Results and Conclusions

Wind Power Assist Without Sale of Surplus Electricity

Results of the economic analysis for wind assist systems indicate that wind turbines may be a viable alternative for irrigators who are using diesel or LP gas pumps in Region A. At the high energy price scenario, and with a 10 percent discount rate, diesel users in Region A

could afford to pay \$132 per square meter before tax savings, if they could not shift to any other conventional fuel. When tax considerations are taken into account, a diesel user in the 25 percent tax bracket in Region A could afford to invest \$161 per m^2 by claiming the business energy and investment tax credits. When the additional first-year depreciation and annual depreciation are included, the investment for wind turbines could be increased to \$192 per m^2 . LPG users in the same situation could afford to pay \$106 per m^2 before the tax savings, and \$154 when all tax credits are claimed. Estimated investment values for all other wind assist situations are much lower (all less than \$75 per m^2) at the medium energy price scenario. Thus, such systems would not be economically attractive unless production costs could be reduced well below the current cost of about \$250 per m^2 for prototype units.

Wind Power Assist With Sale of Surplus Electricity

Wind assist with sale of surplus electricity is more attractive economically than without it. Under this alternative, the investment per m^2 for a wind turbine under the high energy price scenario, with a 10 percent discount rate, ranged from \$217 per m^2 in Region A to \$21 per m^2 in Region G. With all tax credits claimed, the maximum investment per m^2 for wind turbines ranged from \$315 in Region A to \$31 in Region G for a person in the 25 percent federal income tax bracket. Under the medium energy price scenario, the investment ranged from $(-)\$146/m^2$ in Region G to $(-)\$2/m^2$ in Region A, and when federal tax credits were included, it ranged from $\$212/m^2$ in Region A to $(-)\$2/m^2$ in Region G. Investment values appear to be high enough in Region A under both the high and medium energy price scenarios to merit serious considerations. In Region B, the investment values almost merit consideration under the 25 percent federal tax bracket, and they merit serious consideration under the 50 percent federal income tax bracket. In the other regions, the values do not appear high enough to merit serious consideration at this time.

Stand Alone System

The amount that one could afford to invest in wind turbines for a stand alone system was estimated for average conditions in each wind re-

gion. Under the high energy price scenario, the fuel that would be replaced, the maximum before-tax investment value per m^2 and the corresponding wind turbine sizes for each region are as follows: Region A, diesel, $\$702/m^2$, $197 m^2$; Region B, diesel, $\$178/m^2$, $326 m^2$; Region C, natural gas, $\$45/m^2$, $694 m^2$; Region D, electricity, $\$129/m^2$, $830 m^2$; Region E, electricity, $\$78/m^2$, $628 m^2$; Region F, gasoline, $\$91/m^2$, $354 m^2$ and Region G, diesel, $\$143/m^2$, $416 m^2$. Thus, when a high energy price scenario is assumed, stand alone wind systems appear to have reasonable potential for irrigators in Regions A and B who cannot shift to electricity or natural gas, even when federal income tax deductions are not considered. When all federal incentives and taxes are deducted, stand alone wind systems appear to have reasonable potential for irrigators using diesel and LPG in Region A, even under the low energy price scenario. If at least medium energy prices are expected, after tax, wind energy values look attractive for diesel and LPG users in Regions A and B. Under the high energy price scenario, after tax, wind energy values for the diesel user in Region G may also fall within the feasible range. Estimated investment values for all remaining situations are well below the current cost of about $\$250$ per m for prototype wind turbine units.

Other Considerations

This study indicates that producers in several situations may find wind turbines a viable investment, especially producers who must otherwise use diesel or LPG in Regions A and B. There are, however, additional considerations. 1) The results were based on average monthly wind data for broad geographical areas, and may not fit each individual case. (A producer would find it desirable to obtain daily or weekly wind energy values and compare wind energy available to needs for pumping); 2) The performance coefficient of the turbine may vary from the 20 percent used in this study; 3) There may be possibilities for modifying irrigation and crop management practices to take greater advantage of wind power; and 4) The existence of state tax provisions not considered in the study may make wind energy more attractive in particular states.

The above considerations clearly merit further investigation in view of the economic potential that wind energy for irrigation pumping appears

to have. What is provided in this study is essentially a first cut at estimating target investment values. Until more is known about the above factors, significant uncertainties regarding the economic value of wind systems will continue to exist.

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INTRODUCTION

In response to rapidly rising energy costs, farmers have begun looking at alternative systems for pumping irrigation water. Among the alternatives receiving increased attention are wind turbines. The adoption of wind power for irrigation is a choice of technique as well as an investment decision. Unlike more familiar choices of technique - whether or not to use new varieties and whether or not to purchase a more powerful tractor - the adoption of wind energy is subject to enormous technological and economic uncertainties. The technological uncertainties refer to performance characteristics of the wind power system -- how long will it last, what is its likely efficiency in converting wind energy into usable pumping energy, what maintenance costs are required, and so forth. The economic uncertainties refer to future costs, prices and financing: What is the likely cost of wind power systems; what are the likely costs of alternative fuels in the future; is Federal policy likely to equalize the costs of fuels on a BTU basis; what are loan-value ratios, interest rates, term of loan, or tax treatment associated with financing wind energy systems.

The purpose of this study was to address some of the above economic questions and thus reduce some of the uncertainties associated with wind power as an energy source for irrigation. More specifically, the principal objective of the study was to determine the maximum amount which irrigators in different situations could afford to invest in a wind turbine system for pumping irrigation water.

The results of the analysis will provide the U.S. Departments of Energy and Agriculture with target investment costs for wind turbines used for irrigation pumping, and potential users of wind turbines with a basis for deciding when and if they should invest in a wind powered

system. The results could also be used by policy makers who are interested in adjusting tax policy to make alternative sources of energy that substitute for fossil fuels more attractive.

Description of Study Regions

The geographic regions analyzed in this report were selected based on the available wind power and the amount of irrigation. The wind power data were obtained from a Battelle study by Elliot (1977) and data concerning irrigation acreage, number of pumping plants, size of pumping plants, and method of irrigation were obtained from a 1979 irrigation assessment by Gilley (1980).

Location and Quantity of Wind Power by Region

The Great Plains has the greatest potential for utilizing wind energy than of any region in the United States (Figure 1). Elliot (1977), estimates the Great Plains has a mean annual wind power ranging from 350 watts per square meter (W/m^2) to over 500 W/m^2 , at 50 meters above the ground. Other important U.S. irrigation regions have much less potential wind energy. Southern California, the San Joaquin and Imperial valleys, southern Arizona, the Southeast and the Midwest have mean annual wind power of only 200 W/m^2 or less. In Washington, Oregon, and Idaho, where large groundwater irrigated areas exist, the average annual wind power is nearly 300 W/m^2 . In the Great Plains and the Southeast, the maximum wind power occurs in the spring; much of the Pacific States receive wind power in the winter months, with the exception of the San Joaquin Valley.

The Great Plains tend to have higher average wind power during the growing season (May through September) than any irrigated region in the United States, especially during the critical summer months, with 400 W/m^2 (Figure 2). The Pacific Northwest averages 200 W/m^2 during the summer, followed by Southern California and Arizona, with 100 to 200 W/m^2 . The Midwest averages 150 W/m^2 , and the Southeast irrigated areas range from 50 to 150 W/m^2 . Data in Figures 1 and 2 were used only for regional delineation, not for wind power values for irrigation.

Source: Elliot, 1977.

FIGURE 1. Mean annual wind power (W/m^2) estimated at 50 m above exposed areas. Over mountainous regions (shaded areas), the estimates are lower limits expected for exposed mountain tops and ridges.

Source: Elliot, 1977.

FIGURE 2. Summer--Average wind power (W/m^2) estimated at 50 m above exposed areas. Over mountainous regions (shaded areas), the estimates are lower limits expected for exposed mountain tops and ridges.

Region Selection

Typical wind power available during the irrigation season was combined with other factors, such as the length of irrigation season, quantity of irrigation water required during the season, type of irrigation system, size of pumping plant, and type of fuel used for pumping irrigation water, as a basis for the selection of seven Wind Regions (Figure 3). They are:

<u>Wind Regions</u>	<u>Irrigation Season</u>
A. Kansas, Oklahoma, High Plains of Texas, High Plains of New Mexico, and Eastern Colorado.	March - October
B. Nebraska, South Dakota and North Dakota.	April - September
C. South Texas (Edward Plateau) and Pecos Valley of New Mexico.	March - October
D. Southern Arizona and Southern California (primarily the Imperial Valley).	All year
E. Snake and Columbia River Basins in Idaho, Oregon, and Washington.	April - October
F. Midwestern U.S. -- Illinois and Indiana.	June - September
G. Southeastern U.S. -- Florida and Georgia.	March - October

Irrigation Systems

The number of pumping units, by source of energy used to pump irrigation water, are presented for each wind region in Figure 4. Only those sources of energy that represented 15 percent or more of the pumping units were included in the analysis. The number of sprinkler and surface irrigation plants by wind region is shown in Figure 5. The size distribution of the irrigation pumping plants in the seven regions is shown in Figure 6.

Wind-Powered Irrigation Systems

Four types of wind powered irrigation systems were evaluated. They are:

Figure 3. Location of wind energy regions.

Figure 4. Number of pumping units by source of energy and wind region.

Figure 5. Number of pumping units by type of irrigation system by wind region.

Figure 6. Number of pumping units by size of pumping plant by region.

- A. Wind assist combustion engines
 - 1. Diesel
 - 2. Natural Gas
 - 3. Propane
 - 4. Gasoline
- B. Wind assist electric engines, without sale of surplus electricity
- C. Wind assist electric engines, with sale of surplus electricity
- D. Stand alone reservoir system with gravity flow reservoir

METHODS AND PROCEDURES

The general analytical approach used in this study for wind assist systems involved four basic steps: (1) estimates of the amount of wind power available, (2) estimates of the amount of energy that can be harvested by a wind turbine under various conditions, (3) estimates of the economic value of the energy saved and/or sold, and (4) assessment of what irrigators in selected situations could afford to pay for different sized wind turbines. A similar approach was used for analyzing stand alone systems, with two additional steps: calculations of the various combinations of reservoir and turbine sizes necessary to meet water demands for selected situations, and estimates of reservoir construction costs.

Wind Power Available

The monthly wind power available at an elevation of 20 meters for the seven study regions was estimated using the wind data techniques from Reed (1979). The following data were available for each weather station: annual average power, the power at the average annual wind speed, the ratio of these two power values, and average monthly wind speed. These values were tabulated for the anemometer elevation of the particular weather station. Details regarding these data are given in Reed (1979).

The average monthly wind power (PE_i) for a given weather station was calculated by use of the following formula:

$$PE_i = 1/2 \rho (V_i)^3 * \text{RATIO} * \text{DENS} * \text{TEMP}_i \quad [1]$$

where: PE_i = the average monthly power₂ at the given anemometer elevation; W/m^2 .

ρ = the air density, kg/m^3 .

V_i = the average monthly wind speed at the given anemometer elevation, meters/second.

RATIO = the ratio of the average annual power to the power in the annual average wind speed. This value was assumed constant for all months. This correction converts power in the average wind speed to average power.

DENS = the air density correction factor for weather station altitude (Reed, 1979).

TEMP_i = the monthly air temperature correction factor for air density (Reed, 1979).

Average monthly wind power at 20 meters (P_i) was calculated as:

$$PE_i = (20/X)^{3/7} PE_i \quad [2]$$

where: X = the anemometer elevation in meters.

An elevation of twenty meters was selected because this is the USDA recommended height for rural turbines. These above assumptions were necessary to estimate average monthly wind power given the available annual average wind power and average monthly wind speed data from Reed.

The above formula was used to estimate average monthly wind power for each weather station. The average monthly wind power from several weather stations within each of the seven wind regions were averaged to determine the monthly wind power for the selected region. For most regions, at least 10 weather stations were averaged to determine the theoretical available wind power available at 20 meters. The anemometry confidence code given by Reed and the proximity of the weather station to the irrigated area within the region were used to select the weather stations included in the analysis.

Energy Saved

The amount of energy saved with a wind turbine system is essentially dependent upon: the length of time of the operation of the turbine; the geographic location of the turbine (wind power available); and how much energy is harvested per unit of time.

Wind Assist Without Sale

For the wind assisted, no sale alternative, the amount of energy saved per m² per year can be calculated as follows:

$$E = \sum_{j=1}^{12} C_p P_j T_j K_f \quad [3]$$

where:

E = amount of the harvested energy per unit cross sectional area of the turbine, kWh/m² per year.

C_p = performance coefficient for the turbine, dimensionless; (i.e., percent of the available power that is converted to shaft power = 0.2 for this study based on data supplied by the USDA).

P_j = average monthly wind power available per unit area (kW per square meter) for month j .

T_j = monthly hours of operation of the turbine for month j .

K_f = a conversion factor relating the amount of fuel saved to shaft energy, units of fuel per kWh.

fuel	K_f (unit of fuel/kWh shaft energy)*
Diesel	0.341 liter
Propane	0.553 liter
Natural Gas	0.427 m ³
Electric	1.102 kWh

*Fuel efficiency (kWh/unit of fuel) for internal combustion engines decreases with decreasing load.

The above values assumed 85 percent of full load for the internal combustion engines and 90.7 percent average electric motor efficiency.

For the wind assist systems, the wind turbine is assumed to operate simultaneously with the primary power source. Therefore, the turbine would operate for the length of the irrigation pumping season. Representative hours of operation, by month, for the respective wind energy regions were determined from data compiled by James R. Gilley under contract with Southwest Research and Development Company (Gilley, 1980). The data used for computing energy savings reflect average conditions for the respective regions (Table 1). These monthly distributions were

estimated by taking monthly hours of operation for each major crop in the region and computing a weighted average based on the proportion of total irrigated acreage devoted to each crop.

Wind Assist With Sale

For electrical wind-assist systems where surplus energy is sold, the analysis is slightly different, because the turbine would operate continuously. Some of the generated energy would be used directly in the pumping irrigation water. The remaining energy would be sold back to the power supplier at a price different from that used to normally pump irrigation water. Therefore, the total energy contribution (ET) was estimated as equation (1) plus the energy sold (ES). Given:

$$ES = \sum_{j=1}^{12} [C_p P_j (Tt_j - T_j) A] \quad [4]$$

where: ES = electricity sold, kWh/m²/year. *

Tt_j = total hours in month j.

A = alternator efficiency; assumed to be 90 percent.

All other variables as specified in equation [3].

$$\text{then } ET = \sum_{j=1}^{12} [C_p P_j T_j K_f + C_p P_j (Tt_j - T_j) A] \quad [5]$$

Stand Alone System

The energy saved with a stand alone reservoir system (gravity flow) is equal to the total energy requirements of the conventional system:

$$AE = 0.00362 L W \quad [6]$$

where: AE = annual energy saved, kWh

L = meters of head

W = volume of water pumped, m³

Table 1. Wind power available and hours of turbine operation, by region

POWER AND TIME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
<u>REGION A</u>													
Wind Power (kW/m ²)	.378	.424	.560	.544	.432	.406	.296	.258	.323	.319	.367	.344	
Hours - Irrigation	0	0	71	96	224	240	370	419	120	65	0	0	1,605
Hours - Non-Irrigation	744	672	673	624	520	480	374	325	600	679	720	744	7,155
<u>REGION B</u>													
Wind Power (kW/m ²)	.326	.311	.430	.491	.381	.283	.219	.219	.244	.281	.370	.293	
Hours - Irrigation	0	0	0	7	48	114	460	460	247	0	0	0	1,336
Hours - Non-Irrigation	744	672	744	713	606	606	284	284	473	744	720	744	7,424
<u>REGION C</u>													
Wind Power (kW/m ²)	.178	.230	.329	.319	.256	.260	.154	.117	.121	.131	.147	.153	
Hours - Irrigation	0	0	126	310	71	162	350	415	29	58	0	0	1,521
Hours - Non-Irrigation	744	672	618	410	673	558	394	329	691	686	720	744	7,239
<u>REGION D</u>													
Wind Power (kW/m ²)	.178	.230	.329	.319	.256	.260	.154	.117	.121	.131	.147	.153	
Hours - Irrigation	35	98	292	269	279	393	557	522	280	53	91	0	2,869
Hours - Non-Irrigation	709	574	452	151	465	327	187	222	440	691	629	744	5,891
<u>REGION E</u>													
Wind Power (kW/m ²)	.254	.306	.337	.365	.323	.297	.274	.233	.196	.169	.205	.212	
Hours - Irrigation	0	0	0	161	325	463	443	331	142	11	0	0	1,876
Hours - Non-Irrigation	744	672	744	559	395	257	301	413	578	733	720	744	6,884
<u>REGION F</u>													
Wind Power (kW/m ²)	.255	.299	.331	.320	.187	.120	.073	.070	.098	.131	.260	.221	
Hours - Irrigation	0	0	0	0	0	160	240	320	80	0	0	0	800
Hours - Non-Irrigation	744	672	744	720	744	560	504	424	640	744	720	744	7,960
<u>REGION G</u>													
Wind Power (kW/m ²)	.088	.110	.118	.101	.064	.047	.038	.034	.053	.063	.069	.072	
Hours - Irrigation	0	0	358	358	417	118	151	34	375	353	0	0	2,169
Hours - Non-Irrigation	744	672	386	362	327	602	593	710	345	386	720	744	6,591

Reservoir and Turbine Sizing

A stand alone wind system requires a turbine large enough to pump the required water during the course of the year and a reservoir large enough to store the peak monthly difference between inflow and outflow. For any given irrigation situation (water requirements and meters of head), several reservoir-turbine size combinations could be used. As the turbine size increases, the required reservoir size decreases and vice-versa. The question becomes: what is the feasible range of turbine and reservoir sizes for use under average conditions in each wind region?

Reservoir size can be determined with an energy balance technique similar to a flood routing procedure. The inflow of energy, in the form of water, into the reservoir comes from the turbine output. There are two outflows of energy from the reservoir: evaporation losses and irrigation energy water requirements. It was assumed that construction of the reservoir will be such that seepage losses are negligible. The amount of energy stored in the reservoir at anytime is thus the difference between the cumulative inflow and the cumulative outflows. This energy balance relationship can be expressed as:

$$EIS_n = \sum_{j=1}^n [(C_p P_j U T_j) - (EIS_{max} l_j / 3.05) - (IR_j E_p)] \quad [7]$$

where: EIS_n = the amount of energy in storage for month n, kWh

EIS_{max} = the maximum value of EIS_n for the year, kWh

C_p = performance coefficient of turbine (0.2)

P_j = average monthly wind power available, kW/m^2

U = turbine size, m^2

T_j = hours of operation in month j

l_j = net evaporation loss (gross-precipitation) for month j, meters

E_p = energy required to pump one m of water, kWh/m^3
(0.00362 L)

IR_j = the irrigation water requirement of the irrigated area for month j, m

3.05 = the effective storage depth of the reservoir, m

In the above summations, the months are summed with $j=1$ for the last month of the irrigation season, $j=2$ for the next to last, etc.

The above equation was used to estimate an array of turbine and reservoir size combinations for each region. This involved an iterative process, since the value of $EIS_{\max}$ depends upon the size of the turbine. For a given turbine size, the value of $EIS_{\max}$ was determined subject to these constraints: 1) that the turbine could operate a maximum of 12 months, 2) that all energy was depleted from the reservoir at the end of the irrigation season; and (3) the amount of energy in storage was always enough water to meet crop and evaporative demands once the system was started.

Use of the energy balance equation required developing estimates for the following parameters:

1. pumping lift
2. monthly irrigation water demands
3. monthly gross lake evaporation
4. monthly precipitation
5. monthly wind power available
6. average peak weekly water use rate
7. size of area irrigated per wind system

Estimates of the above parameters were developed for average conditions in each wind region (Appendix A, Tables A-1 to A-7). Pumping lifts, irrigation water demands, peak weekly water use rates and the size of area irrigated per wind system were computed primarily from the results of the irrigation assessment (Gilley, 1980). The monthly precipitation figures used in the analysis were weighted averages (weighted by irrigated area) of the state level data reported in the Climate Atlas (1968). Monthly lake evaporation estimates were developed using the following Blaney Criddle equation:

$$l_j = (1.8 T_j + 32) p_j / 3937 \quad [8]$$

where: l_j = estimated lake evaporation in month j , meters

T_j = mean monthly air temperature, in degrees Celsius

p_j = mean monthly percent of annual daytime hours

In selecting the T_j and p_j values for each wind region a single location in the center of the irrigated area within the region was used.

The final step in computing turbine versus reservoir size combinations for each region consisted of selecting a finite array of possibilities for each region. This was done by first selecting maximum and minimum feasible reservoir and turbine sizes and then choosing enough points between the two extremes to enable plotting reasonable curves.

It was assumed that a turbine of the maximum size would supply the average peak weekly energy requirement. A turbine of the minimum size would have to operate all year to supply the amount of energy required.

The maximum reservoir size used in the analysis corresponded to the minimum turbine size. It was assumed that the minimum reservoir would have to be large enough to hold at least one day of water use at the average peak weekly use rate for the area irrigated.

The resulting reservoir versus turbine size combination for the seven regions are shown in Appendix A in both tabular (Tables A-1 to A-7) and graphic form (Figures A-1 to A-7). The range of turbine sizes goes well beyond what is feasible mechanically. "Impossible" turbine sizes were included so that a complete range of economic tradeoffs between reservoir costs and turbine size could be shown for each region.

Economic Analysis

The acquisition of a wind turbine involves making a substantial initial investment that will produce benefits over a long period of time (20 years). Thus, the timing of the cost and returns must be considered in the economic analysis. The discounted cash flow technique was used in the study, as it enables all the future cash flows to be discounted to the present values by use of an interest rate that may approximate the irrigator's cost of capital. The present value computations represent the amount an irrigator can pay based on that stream of anticipated future annual returns.

Energy Price Scenarios

Three energy price scenarios for each fuel source were used in the analysis. Specification of these price scenarios involved first determining an average current price for each fuel source in each region. The initial prices were then increased at varying rates over time to reflect possible future conditions.

Average base prices for diesel, gasoline, and liquid petroleum gas (LPG) for each region were estimated from USDA data by weighting the average price for each state by region by the proportion of total regional irrigated areas in that state (Table 2). The base price data for natural gas were obtained, by region, for late 1979 and early 1980, from the American Gas Association Rate Services and were adjusted to January, 1980 prices. The base price data for electricity, by region, were obtained by telephone interviews with relevant state agencies in the study regions (Table 2). The value of surplus electricity produced to be sold to local utilities was estimated by USDA and USDOE personnel to be 60 percent

Table 2. Energy price, by source and region, January 1980

January 1980 Energy Price						
Region	Diesel	Gasoline	LPG	Natural Gas	Electricity	Surplus Electricity
	- - - - - \$/liter - - - - -			\$/Mfm ³	- - - - - ¢/kWh - - - - -	
A	0.24	--	0.13	0.064	4.5	2.7
B	0.24	--	--	0.043	4.0*	2.4
C	0.23	--	--	0.059	4.5	2.7
D	0.23	--	--	0.068	4.6	2.8
E	--	--	--	--	3.15	1.9
F	0.25	0.28	0.15	--	5.6	3.4
G	0.26	--	--	--	7.9	4.7

* Plus \$17.43 per installed kilowatt capacity of the electric motor.

of the price irrigators pay for electricity for irrigation pumping. This value is higher than the typically quoted 40 to 50 percent of electricity purchases. However, it was assumed that some of the surplus electricity

would be used by the farmer for other farm uses, thus increasing the blend value to about 60 percent of the retail price.

The three 20-year price scenarios (high, medium, and low) were developed in consultation with the personnel from USDA and USDOE.

The high energy price scenario is the maximum expected energy price increases in real terms over the next 20 years. The high energy price scenario projections were:

Fossil Fuels: January, 1980 energy prices are compounded at a rate of 35 percent per year for two years and then at a rate of 8 percent per year thereafter.

Electricity: January, 1980 electricity rate price is compounded at a rate of 20 percent per year for two years and then at 4 percent per year thereafter.

The low energy price scenario is the minimum real energy price increases that could be expected for the next 20 years. The energy price projections for this alternative are as follows:

Fossil Fuel: Prices were increased at an annual compounded rate of 4 percent per year for the entire 20-year period.

Electricity: Prices were increased at an annual compounded rate of 2 percent per year for the entire 20-year period.

A medium energy price scenario was developed for sensitivity analysis. The energy projections for this scenario were:

Fossil fuel: Prices were increased at an annual compounded rate of 8 percent per year for the entire 20-year period.

Electricity: Prices were increased at an annual compounded rate of 4 percent per year for the 20-year period.

Breakeven Investment Values for Wind-Assist Systems

The central economic question to be analyzed is, How much can irrigators in each situation (wind region and fuel source) afford to pay for wind machines of different sizes? An answer to this question can be conceptualized as follows for all wind assist, including sale of or no sale of surplus electricity.

$$V_i = \sum_{t=1}^{20} \frac{E_i Pe_{it} + ES_i Pes_{it} - M}{(1+r)^t} \quad [9]$$

where: V_i = investment value in dollars per square meter of turbine for case i, before taxes.

t = time in years (20 years for system life was assumed based on consultation with personnel from USDA)

E_i = units of energy saved in case i (from Eq. 3)

Pe_{it} = energy price for case i in year t (price of energy saved)

ES_i = units of energy sold in case i (from Eq. 4)

Pes_{it} = energy price for case i in year t (price of energy sold)

M = operation and maintenance charge (\$10/m²). This figure is a preliminary judgement of officials from USDA who have experience with experimental turbines)

r = discount rate (7 and 10 percent)

Breakeven Investment Values for Stand Alone Systems

Analysis of the stand alone-reservoir system is more complicated than the wind assist system. With this system, the amount that irrigators could pay for a wind turbine equals the present value of the fossil fuel savings, plus the present value of the savings from displacing a conventional power unit, minus reservoir costs. For any given reservoir size and set of wind region parameters (k), the investment value of the corresponding turbine size (U) can be expressed as:

$$I_{uk} = \sum_{j=1}^n \frac{FS Pe_i + C - MU - R}{(1+r)^n}$$

where: I_{uk} = investment value of turbine size U in wind region k in 1980 dollars

FS = units of fuel saved

Pe_i = price of fuel per unit in year i

C = annual savings from avoiding the cost of a conventional power plant

M = annual maintenance charge/ m^2 , assumed to be \$10/ m^2

U = turbine size in m^2

R = reservoir construction costs

n = assumed 20-year project life

Estimates of fuel saved (FS) were based on the energy required to lift the average water requirement in each region a given average lift (see Appendix A, Tables A-1 to A-7).

The annual savings due to replacement of a conventional power plant (C) were equal to the amortized investment cost at 10 percent interest, plus a 5 percent operation and maintenance allowance. The investment costs used for each engine size were from data compiled by Extension economists at the University of Nebraska-Lincoln in early 1980.

Reservoir construction costs (R) were estimated by computing the amount of rolled fill material required and the surface area that would be lined for each reservoir size, and multiplying times \$1.08 per cubic meter for the fill material and \$1,215 per hectare for lining. It was assumed that each side of a square reservoir would be 2.4 meters wide on top, 3.05 meters high and 14.6 meters wide at the bottom. The unit costs used were expected averages, based on the recent experience of the Soil Conservation Service, USDA.

Project life was assumed to be 20 years for both the wind turbine and the reservoir.

Effect of Taxes on Investment Values

Federal income tax provisions strongly affect the economic feasibility of an investment such as a wind turbine. Tax savings generated by

the investment can be added to the savings from reduced fuel requirements and revenues from possible surplus power sales. Adding the tax savings increases the amount that an irrigator can afford to pay for a wind turbine. The magnitude of this increase depends on the irrigator's marginal tax bracket. The irrigators in the highest tax bracket could justify the highest investment in wind turbines.

Because of the widely varying income positions of irrigators in each region, it is not possible to select a single set of parameters as typical after tax conditions. Thus, for purposes of this study, a set of adjustment factors was computed for a variety of tax situations (table 3). These adjustment factors, when multiplied by the results of equations 9 and 10, indicated what producers in the various tax and irrigation situations could afford to pay for wind turbines.

Six different federal tax situations were considered at two different depreciable lives, 10-year and 20-year (see table 3 for a list). The results indicate that tax considerations increase investment values by as much as 108 percent for someone in the 50 percent tax bracket who takes all credits he is entitled to and uses a 10-year depreciation schedule, plus 20-percent additional first-year depreciation. Probably more typical would be an investor in the 25-percent tax bracket with enough income to take all credits he is entitled to, who elects to use a 10-year depreciation schedule with 20-percent additional first-year depreciation. Someone in this circumstance could afford to pay about 54 percent more than the estimated beforetax values for a wind turbine.

Typical Size and Cost of Wind Turbines

Typical turbine size for irrigation is expected to range from 75 to 300 square meters. Table 4 presents conversions from size of turbines in square meters to diameter in meters, and power level at a wind speed of 10 meters per second in kilowatts. For example, a 200 m² turbine is 15.96 meters in diameter and would be rated at 24 kilowatts.

The only information currently available on the cost of wind turbines is that associated with experimental units. Such units currently cost approximately \$250 per square meter of turbine area for a commercial sized unit. The total investment an irrigator would have to make, however, is

Table 3. Adjustment factors for converting before-tax investment values to after-tax values at different tax rates and depreciation schedules*

Tax situation (Federal)	Depreciable Life	
	10 years	20 years
Before tax	1.0	1.0
With only BETC or IC**	1.0999	1.0999
With both BETC and IC	1.2222	1.222
With BETC, IC and depreciation savings		
25% tax rate	1.5047	1.4049
50% tax rate	1.9571	1.6519
With BETC, IC, AFYD and depreciation savings		
25% tax rate	1.5388	1.4543
50% tax rate	2.0768	1.7953

* Assumes a 10 percent discount rate and straight line depreciation. The factors listed can be multiplied by the before tax investment values to yield after tax investment values.

** BETC means business energy tax credit (currently 10%); IC means investment credit (currently 10%); and AFYD means additional first year depreciation (20% of asset basis).

Table 4. Conversion sizes of turbines (square meters) to diameter (meters) to power level at a wind speed of 10 meters per second

Size of Turbine	Diameter of Turbine	Power Level at a Wind Speed of 10 m/second
(m ²)	(m)	(kilowatts)
25	5.64	3
50	7.98	6
75	9.77	9
100	11.28	12
125	12.62	15
150	13.82	18
175	14.93	21
200	15.96	24
300	19.54	36
400	22.57	48
500	25.23	60
1,000	35.68	120

dependent on the size required for his particular situation. The typical irrigation systems would probably require a unit 75 m² (9 kW) in size to 300 m² (36 kW), depending on energy requirements and available wind power. Thus, the total investment for a typical wind assist system is probably in the \$18,750 - \$75,000 range, by current prices. When, and if, wind turbines become available in commercial quantities, these costs will likely decrease significantly.

The total investment for stand alone systems would be much higher because of larger turbine requirements and reservoir construction costs.

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RESULTS

The results will be presented first for energy saved by wind-powered turbines for irrigation pumping, followed by the amount of surplus electricity available for sale. Then, an economic analysis will be presented by type of wind-powered irrigation system - wind assist without sale of surplus energy, wind assist with sale of surplus electricity and stand alone reservoir system with gravity flow from reservoir. In addition, the effect of federal taxes and incentives on investment values will be discussed.

Amount of Energy Saved

The estimated amount of energy saved per square meter of turbine size from assisting conventionally powered irrigation pumping units with wind turbines ranged from 13 kWh/m² per year in Region F to 117 kWh/m² in Region D (Figure 7). It was 113 kWh/m² in Region A, 77 in Region B, 57 in Region C, 106 in Region E, and 32 kWh/m² in Region G.

Amount of Surplus Electricity Available for Sale

The amount of electricity available for sale or use on the farm from the wind turbine when irrigation pumping is not required ranged from 565 kWh/m² for Region A to 93 kWh/m² for Region G (Figure 7). It was 488 kWh/m² for Region B, 291 for Region C, 232 for Region D, 356 for Region E, and 331 kWh/m² for Region F.

Breakeven Investment Values

The amount one could invest in wind turbines was estimated for average conditions - monthly average wind power, average performance of wind turbines, and average base prices for conventional energy.

Wind Assist Without Sale of Surplus Electricity

Under this alternative, in the before-federal-tax investment per square meter of turbine to replace conventional fuels,

Figure 7. The potential amount of energy saved from using wind turbines for pumping irrigation and the amount of surplus electricity available for sale from the use of wind turbines by region.

Table 5. Investment Value Per Square Meter for Wind Assist Turbines by Energy Source and Energy Price Scenario, by Region.

Wind Region	Discount (percent)	Diesel			Gasoline			LPG			Natural Gas			Electricity		
		Price Scenario*			Price Scenario*			Price Scenario*			Price Scenario*			Price Scenario*		
		H	M	L	H	M	L	H	M	L	H	M	L	H	M	L
dollars per square meter																
A	10	132	59	20	--	--	--	106	42	8	4	-26	-42	-10	-25	-33
	7	186	86	29	--	--	--	151	63	14	13	-28	-51	-8	-29	-40
B	10	61	12	-14	--	--	--	--	--	--	-44	-58	-65	-37	-46	-51
	7	91	23	-15	--	--	--	--	--	--	-51	-70	-80	-44	-56	-63
C	10	-44	-58	-65	--	--	--	--	--	--	-44	-58	-65	-44	-50	-55
	7	-51	-70	-80	--	--	--	--	--	--	-51	-70	-80	-53	-64	-69
D	10	--	--	--	--	--	--	--	--	--	13	-20	-38	-5	-22	-30
	7	--	--	--	--	--	--	--	--	--	25	-20	-45	-3	-25	-36
E	10	--	--	--	--	--	--	--	--	--	--	--	--	-34	-44	-48
	7	--	--	--	--	--	--	--	--	--	--	--	--	-39	-53	-60
F	10	-59	-68	-73	-44	-58	-65	-60	-68	-73	--	--	--	-69	-71	-72
	7	-71	-83	-89	-50	-69	-79	-72	-84	-90	--	--	--	-85	-88	-90
G	10	-20	-42	-53	--	--	--	--	--	--	--	--	--	-44	-52	-55
	7	-18	-48	-65	--	--	--	--	--	--	--	--	--	-54	-64	-69

* H = higher price scenario, where January 1980 energy source price for fossil fuels are compounded at a rate of 35 percent for two years and then 8 percent per year for 18 years. For electricity the price is compounded at 20 percent per year for two years and then 4 percent per year for 18 years.

M = medium price scenario, where January 1980 fossil fuel price is 8 percent per year for 20 years and electricity price is compounded at a rate of 4 percent per year for 20 years.

L = low price scenario, where January 1980 fossil fuel price is compounded at a rate of 4 percent per year for 20 years and electricity price is compounded at a rate of 2 percent per year for 20 years.

under the high energy price scenario for diesel, with a 10 percent discount rate, ranged from $\$132/\text{m}^2$ in the windiest region, the Southern High Plains (Region A), to a negative $(-)\$59/\text{m}^2$ for the Midwest (Region F); for LPG, from $\$106/\text{m}^2$ in Region A to $(-)\$60/\text{m}^2$ in Region F; for natural gas, from $\$13/\text{m}^2$ in Southern Arizona and Southern California (Region D) to $(-)\$44/\text{m}^2$ in the Northern High Plains and Edwards Plateau of Texas and the Pecos River Basin of New Mexico (Regions B and C); and for electricity, from $(-)\$5/\text{m}^2$ in Region D to $(-)\$69/\text{m}^2$ in Region F (Table 5).

Under the medium price scenario, however, the investment values dropped to less than 50 percent of the values under the high price scenario for most fuels, and were even lower under the low energy price scenario.

Under the high energy price scenario, at a discount rate of 7 percent, investment values for diesel ranged from $\$186/\text{m}^2$ in Region A to $(-)\$79$ in Region F; for LPG, from $\$151/\text{m}^2$ in Region A to $(-)\$79/\text{m}^2$ in Region F; for natural gas, from $\$25/\text{m}^2$ in Region D to $(-)\$51/\text{m}^2$ in Regions B and C; and for electricity, from $(-)\$3/\text{m}^2$ in Region D to $(-)\$85/\text{m}^2$ in Region F. The investment values were lower under the medium and low energy price scenarios. The negative investment values indicate that the discounted fuel savings would not cover the discounted operation and operation costs of $\$10/\text{m}^2$.

When tax savings are considered, a diesel using irrigator in the high wind power region (Region A), who is in a 25 percent federal tax bracket, and only claims business energy tax credit and investment credit could afford to invest $\$161/\text{m}^2$ instead of the before tax savings of $\$132/\text{m}^2$. If the additional first-year depreciation and annual depreciation were included, the investment for wind turbines would increase to $\$192/\text{m}^2$.

LPG users in the same tax situation could afford to invest $\$106/\text{m}^2$ in the before-tax case, or $\$154$ when all tax credits are claimed. Investment values for all other wind assist situations were much lower (all less than $\$75/\text{m}^2$) at the medium energy price scenario. These systems would not be economically attractive unless production costs could be reduced well below the current cost of about $\$250/\text{m}^2$ for prototype units, even including federal tax considerations.

The best opportunities appear to be to replace diesel and LPG in the Southern High Plains (Region A) and diesel in the Northern High Plains (Region B). Replacing conventional sources of energy with wind power does not appear to be a viable alternative in any of the other regions.

Replacing gasoline or electricity do not appear to be viable alternatives in any region or scenario. Gasoline is used in any large quantities only in the Midwest, where irrigation is supplemental, and is used only for short periods in the irrigation season. Electricity is a relatively cheap source of energy for most areas under investigation. The most negative investment values of wind turbines were found for replacing electricity in the two supplemental irrigated areas (South and Midwest), closely followed by Region C.

Figures B-1 through B-5 in Appendix B present the investment that irrigators could afford to make, by turbine size, energy price scenario, and region. The figures were prepared only for the alternatives in which the discounted investment values were positive (Table 5). For example, an irrigator requiring an 18 kilowatt wind turbine (the turbine size conversion from square meters to kilowatts in Table 4 shows this to be 150 m^2), could afford to invest \$19,800, without federal tax considerations, for a 150 m^2 wind turbine in Region A to replace a diesel powered pumping unit, under the high energy price scenario, with a 10 percent discount rate; \$8,850 under the medium energy price scenario; and only \$3,000 under the low energy price scenario (Figure B-1). Similar maximum investment values can be obtained from Figures B-2 through B-5 for the various regions, energy types, and energy price scenarios.

Wind Assist With Sale of Surplus Electricity

Wind assist with sale of surplus electricity is more attractive economically than wind assist alone (Table 6). Under this alternative, the investment per square meter for a wind turbine under the high energy price scenario, with a 10 percent discount rate, ranged from $\$217/\text{m}^2$ in Region A to $\$21/\text{m}^2$ in Region G (Table 6). It was $\$137/\text{m}^2$ in Region B, $\$73/\text{m}^2$ in Region C, $\$89/\text{m}^2$ in Region D, $\$66/\text{m}^2$ in Region E, and $\$97/\text{m}^2$ in Region F.

Table 6. Investment Values Per Square Meter for Wind Assist Turbines
Selling Surplus Electricity by Energy Price Scenario and Region

Wind Region	Discount Rate (percent)	Energy Price Scenario		
		High	Medium	Low
		- - -dollars per square meter - -		
A	10	217	146	115
	7	285	192	148
B	10	137	85	63
	7	181	113	81
C	10	73	38	22
	7	98	50	28
D	10	89	50	32
	7	120	68	43
E	10	66	32	18
	7	90	42	23
F	10	97	54	36
	7	128	73	47
G	10	21	-2	-7
	7	30	0	-5

When all tax credits (BETC, IC, AFYD, and depreciation) were claimed, the maximum investment per square meter for wind turbines ranged from \$315 in Region A to \$31 in Region G for an irrigator in the 25 percent federal income tax bracket. Under the medium price scenario, the investment ranged from (-)\$2/m² in Region G to \$146/m² in Region A without federal tax and investment credits, and from \$1/m² in Region G to \$212/m² in Region A with federal tax credits.

Investment values appear to be high enough in Region A under both the high and medium energy price scenarios to merit serious considerations. Under the high energy price scenario, in Region B, wind turbines almost merit consideration if the irrigator is under the 25 percent federal tax bracket, and they merit consideration for irrigators under the 50 percent federal income tax bracket. It appears that no other region merits serious consideration at this time.

The investment values under the high energy price scenario without federal tax and incentive considerations, were even higher when a 7 percent discount rate was used, ranging from \$285/m² in Region A to \$30/m² in Region G (Table 6).

Figures C-1 through C-7 in Appendix C present the investment values that farmers could afford in wind turbines, by turbine size, energy price scenario, discount rate, and wind region. For example, an irrigator could afford to pay \$32,550 for a 150 m² (18 kWh) wind turbine in Region A to replace a conventional energy powered pumping unit, under the high energy price scenario (Figure C-1). Similar maximum investment values can be obtained from Figures C-2 through C-7 for the various regions and energy price scenarios.

Stand Alone System

The amount one could afford to invest in wind turbines for a stand alone system was estimated for average conditions in each region, under three energy price scenarios for each major energy source. If the high energy price scenario is expected, the maximum before-tax investment value per square meter and the corresponding wind turbine sizes to replace the energy source in each region are: Region A, diesel, \$702/m², 197.2 m²; Region B, diesel, \$178/m², 326.3 m²; Region C, natural gas, \$45/m², 694.5 m²; Region D, electricity, \$129/m², 830.7 m²; Region E, electricity, \$78/m², 628.0 m²; Region F, gasoline, \$91/m², 354.5 m²; and Region G, diesel, \$143/m², 416.5 m² (Table 7).

The maximum value of wind turbines is much lower in most regions, if one interprets the data more conservatively. Assuming that the maximum turbine size that is feasible in either a physical or an economic sense is about 250 m², and further assuming that all liquid fuels are available to each irrigator, the maximum values for Regions A through G, at the high energy price scenario, without federal tax considerations, and at 10 percent interest, are \$573, \$150, \$0, \$0, \$75, and \$0 per square meter, respectively, and \$805, \$230, \$2, \$0, \$0, \$115, and \$0 per square meter, respectively, when all tax credits are claimed by an irrigator in the 25 percent federal income tax bracket. Under the medium price scenario rates, the highest values, by region, are \$344, \$51, \$0, \$0, \$0, \$7, and

Table 7. Investment value per square meter for stand alone wind systems by region, energy source and energy price scenario at a 10 percent discount rate

Reservoir Size m ³ (000 m ³)	Turbine Size m ²	Diesel			Gasoline			LPG			Natural Gas			Electricity		
		Price Scenario			Price Scenario			Price Scenario			Price Scenario			Price Scenario		
		High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low	High	Medium	Low
(dollars per square meter)																
WIND REGION A																
159	147	702	333	140	--	--	--	573	248	77	1	--	--	--	--	--
148	157	684	338	157	--	--	--	563	258	98	27	--	--	-17	--	--
136	168	667	344	174	--	--	--	554	269	119	52	--	--	11	--	--
123	181	642	343	186	--	--	--	538	274	135	73	--	--	35	--	--
111	195	622	343	197	--	--	--	524	278	149	92	-22	--	57	-13	--
99	215	585	332	199	--	--	--	496	273	156	104	1	--	72	9	-20
74	276	492	295	191	--	--	--	423	249	158	117	37	-5	93	43	21
49	350	417	262	181	--	--	--	363	226	157	122	59	26	103	64	46
31	406	381	247	177	--	--	--	334	216	157	127	72	44	110	76	61
19	443	364	241	177	--	--	--	321	213	156	131	81	55	115	85	71
17	445	363	241	177	--	--	--	320	212	156	131	81	55	115	85	71
12	847	194	130	97	--	--	--	172	115	86	73	46	33	64	48	41
6	1,317	128	87	66	--	--	--	114	78	59	50	33	25	45	35	30
WIND REGION B																
140	93	-35	--	--	--	--	--	--	--	--	--	--	--	--	--	--
148	122	45	--	--	--	--	--	--	--	--	--	--	--	--	--	--
121	152	98	-50	--	--	--	--	--	--	--	--	--	--	--	--	--
99	182	132	10	--	--	--	--	--	--	--	--	--	--	--	--	--
74	224	150	51	-1	--	--	--	--	--	--	--	--	--	--	--	--
49	271	163	81	38	--	--	--	--	--	-36	--	--	--	-1	-25	-36
25	318	176	106	69	--	--	--	--	--	6	--	--	--	30	15	6
20	326	178	110	75	--	--	--	--	--	13	-6	--	--	42	22	13
12	462	136	88	63	--	--	--	--	--	19	6	-2	--	40	26	19
6	567	118	79	59	--	--	--	--	--	23	12	6	--	40	29	23
5	592	115	78	58	--	--	--	--	--	24	14	8	--	40	29	24
WIND REGION C																
80	232	--	--	--	--	--	--	--	--	-7	--	--	-10	--	--	--
74	257	--	--	--	--	--	--	--	--	4	--	--	0	--	--	--
62	323	--	--	--	--	--	--	--	--	19	-21	--	16	-1	-11	--
43	455	--	--	--	--	--	--	--	--	31	3	--	29	10	2	--
31	544	--	--	--	--	--	--	--	--	37	13	--	35	19	12	--
19	633	--	--	--	--	--	--	--	--	42	21	10	40	27	21	--
12	678	--	--	--	--	--	--	--	--	44	25	15	43	30	25	--
10	694	--	--	--	--	--	--	--	--	45	27	17	44	32	26	--
6	1,557	--	--	--	--	--	--	--	--	22	14	9	22	16	13	--
4	2,020	--	--	--	--	--	--	--	--	18	11	8	17	13	11	--
WIND REGION D																
223	700	--	--	--	--	--	--	--	--	115	34	-8	128	70	44	--
197	767	--	--	--	--	--	--	--	--	117	43	4	128	75	51	--
173	831	--	--	--	--	--	--	--	--	118	50	14	129	80	58	--
111	1,111	--	--	--	--	--	--	--	--	108	58	21	116	80	63	--
74	1,321	--	--	--	--	--	--	--	--	102	59	37	109	78	64	--
49	1,500	--	--	--	--	--	--	--	--	97	59	40	103	76	64	--
25	1,678	--	--	--	--	--	--	--	--	93	60	42	99	75	64	--
25	1,706	--	--	--	--	--	--	--	--	92	59	42	97	74	63	--
12	2,399	--	--	--	--	--	--	--	--	68	45	33	77	55	40	--
6	2,762	--	--	--	--	--	--	--	--	61	41	30	64	50	42	--
WIND REGION E																
148	371	--	--	--	--	--	--	--	--	--	--	--	-6	--	--	--
123	411	--	--	--	--	--	--	--	--	--	--	--	16	-18	--	--
99	451	--	--	--	--	--	--	--	--	--	--	--	36	5	-9	--
74	508	--	--	--	--	--	--	--	--	--	--	--	51	23	11	--
49	537	--	--	--	--	--	--	--	--	--	--	--	64	39	28	--
25	623	--	--	--	--	--	--	--	--	--	--	--	77	55	44	--
22	628	--	--	--	--	--	--	--	--	--	--	--	70	58	46	--
12	1,003	--	--	--	--	--	--	--	--	--	--	--	55	41	35	--
6	1,141	--	--	--	--	--	--	--	--	--	--	--	40	37	32	--
WIND REGION F																
86	112	--	--	--	-60	--	--	--	--	--	--	--	--	--	--	--
74	140	--	--	--	48	--	--	--	--	--	--	--	--	--	--	--
62	180	-20	--	--	66	-21	--	--	--	--	--	--	--	--	--	--
49	230	8	--	--	75	7	--	-15	--	--	--	--	--	--	--	--
37	280	26	-5	-21	81	26	-3	8	--	--	--	--	--	--	--	--
25	330	41	15	1	87	40	16	25	-1	--	--	--	--	--	--	--
19	355	47	23	10	91	47	24	33	9	-4	--	--	--	--	--	--
14	389	51	29	17	91	51	30	38	14	4	--	--	--	--	--	--
12	500	41	24	14	17	41	24	31	14	5	--	--	--	-1	-5	-7
5	1,236	20	13	10	32	20	13	16	9	6	--	--	--	2	2	1
WIND REGION G																
06	300	118	36	-7	--	--	--	--	--	--	--	--	-1	--	--	--
80	312	122	43	2	--	--	--	--	--	--	--	--	7	--	--	--
74	323	125	49	9	--	--	--	--	--	--	--	--	14	--	--	--
62	352	129	60	23	--	--	--	--	--	--	--	--	27	-5	--	--
49	382	133	69	15	--	--	--	--	--	--	--	--	39	9	-2	--
37	417	143	84	53	--	--	--	--	--	--	--	--	57	29	19	--
25	502	124	76	50	--	--	--	--	--	--	--	--	53	30	22	--
12	604	115	74	53	--	--	--	--	--	--	--	--	56	37	30	--
11	614	114	74	54	--	--	--	--	--	--	--	--	56	38	30	--
6	1,530	48	32	24	--	--	--	--	--	--	--	--	25	17	14	--
4	1,899	40	27	20	--	--	--	--	--	--	--	--	21	15	13	--

\$0 per square meter, respectively, without federal tax considerations, and \$530, \$73, \$0, \$0, \$11, and \$0, respectively, when all tax credits are claimed by the irrigator in the 25 percent federal income tax bracket.

Detailed results showing the relationship between turbine size and investment value per square meter at different energy price scenarios are presented graphically in Figures D-1 through D-7 in Appendix D. Generally, the results indicate that the highest values per meter occur at the smallest feasible turbine sizes for the regions with the most wind power. As the amount of wind power decreases, the highest value turbine size increases, with all other factors held constant. Another observation is that the curves with the highest investment values per square meter tend to occur at higher turbine sizes under the lower energy price scenarios, unless the monthly use rate limit (discontinuity) is reached first.

Stand alone wind systems appear to have reasonable potential in wind regions A and B for irrigators who cannot shift to electricity or natural gas. Estimated investment values for all situations in the other five regions are well below the current cost of about $\$250/\text{m}^2$ for prototype wind turbine units.

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CONCLUSIONS

An irrigator anticipating the replacement of a conventionally powered irrigation pumping unit should consider the costs of alternative source of conventional energy before deciding to invest in wind turbines. For example, electricity and natural gas had economic advantages over wind power under all energy price scenarios in this study. If electricity or natural gas is immediately available without large hook-up charges, then, clearly, their use is a less expensive method for pumping irrigation water.

The best opportunities appear to replace diesel and LPG in the Southern High Plains (Region A) and diesel in the Northern High Plains (Region B). Investment values appear to be high enough for wind-assist with and without sale of surplus electricity in Region A under both the high and medium energy price scenario, for the replacement of diesel and LPG. Under the high energy price scenario in Region B, wind turbines almost merit consideration for replacing diesel, if the irrigator is under the 25 percent federal tax bracket, and they merit consideration for irrigators under the 50 percent federal income tax bracket. It appears that no other region merits serious consideration at this time for wind assist irrigation systems.

Wind assist with sale of surplus electricity is more attractive economically than without it. Under this alternative, the investment per m^2 for a wind turbine under the high energy price scenario, with a 10 percent discount rate, ranged from \$217 per m^2 in Region A to \$21 per m^2 in Region G. With all tax credits claimed, the maximum investment per m^2 for wind turbines ranged from \$315 in Region A to \$31 in Region G for a person in the 25 percent federal income tax bracket. Under the medium energy price scenario, the investment ranged from $(-)\$146/m^2$ in Region G to $(-)\$2/m^2$ in Region A, and when federal tax credits were included, it ranged from $\$212/m^2$ in Region A to $(-)\$2/m^2$ in Region G. Investment values appear to be high enough in Region A under both the high and medium energy price scenarios to merit serious considerations. In Region B, the investment values almost merit consideration under the 25 percent federal tax bracket, and they merit serious consideration under the 50 percent federal income tax bracket. In the other regions, the values do not appear high enough to merit serious consideration at this time.

Replacing conventional fuels does not appear to be a viable alternative in any of the other regions. Gasoline appears to be used in large quantities only in the Midwest, where irrigation is only supplemental, and is only used for short periods during the irrigation season. Electricity is a relatively cheap source of energy for most areas under investigation.

Stand alone wind systems appear to have reasonable potential in Regions A and B for irrigators who cannot shift to electricity or natural gas. When all federal incentives and taxes are deducted, stand alone wind systems appear to have reasonable potential for irrigators using diesel and LPG under the medium and low energy price scenarios in Region A, medium energy price scenario in Region B, and the high energy price scenario for diesel in Region G. Estimated investment values for all situations in the other four regions are well below the current cost of about $\$200 \text{ m}^2$ for prototype wind turbine units.

What irrigators can afford to pay for wind turbines depends not only on what they are worth, but also on the irrigator's ability to finance them. The fact that something is a good investment is of little significance unless it is also possible for potential investors to acquire the necessary capital. The potential investors must either have the necessary cash or be able to borrow the money under terms consistent with their repayment capacity.

Generally speaking, it seems unlikely that potential investors would have trouble financing wind systems. Generally, wind turbines would probably be purchased in particularly good income years so that only a small part, if any, of the required funds would need to be borrowed. A second consideration is that the size of the investment, e.g., $\$50,000$ ($200 \text{ m}^2 \times \$250/\text{m}^2$), is small relative to the cost of other items used in today's agriculture. Still another factor that diminishes the likelihood of financing problems is the fact that irrigators almost always have the option of using their land equity to finance long-term needs if other alternatives are not feasible or attractive.

This study indicates that producers in several situations may find wind turbines a viable investment, especially producers who must otherwise use diesel or LPG in Regions A and B. There are, however, additional

considerations. 1) The results were based on average monthly wind data for broad geographical areas, and may not fit each individual case (A producer would find it desirable to obtain daily or weekly wind energy values and compare wind energy available to needs for pumping.); 2) The performance coefficient of the turbine may vary from the 20 percent used in this study; 3) There may be possibilities for modifying irrigation and crop management practices to take greater advantage of wind power; and 4) The existence of state tax provisions not considered in the study may make wind energy more attractive in particular states.

The above considerations clearly merit further investigation in view of the economic potential that wind energy for irrigation pumping appears to have. What is provided in this study was essentially a first cut at estimating target investment values for wind turbines for pumping irrigation water. Until more is known about the above factors, significant uncertainties regarding the economic value of wind systems will continue to exist.

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APPENDIX A

Turbine and Reservoir Sizing Analysis

Table A-1. TURBINE AND RESERVOIR SIZING ANALYSIS
FOR: REGION A AVERAGE

INPUT DATA:

RESERVOIR SIZING ASSUMPTIONS, METER:

TOP WIDTH	2.4	BOTTOM WIDTH	14.6	DEPTH	3.0
LIFT, METER				76.2	
PEAK WATER USE RATE, CM/DAY				1.27	GROSS
MONTH OF PEAK WATER USE RATE				AUG	
AREA IRRIGATED WITH SIMULATED SYSTEM				46.5	HA
IRRIGATION EFFICIENCY, DECIMAL				0.700	

MONTHLY VALUES

	JAN	FEBR	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
WIND POWER KW/SQ M	.378	.424	.560	.544	.432	.406	.296	.258	.323	.319	.367	.344
LAKE EVAP., CM/MON	5.9	6.4	9.9	13.2	17.4	20.1	21.8	20.4	15.8	12.0	8.1	6.3
RAINFALL, CM/MON	1.2	1.4	2.1	4.2	7.8	6.6	5.7	6.2	3.3	3.0	1.7	1.2
IRR. GROSS, CM/MON	0.0	0.0	2.8	3.8	9.1	9.7	15.0	17.0	4.8	2.5	0.0	0.0

RESULTS:

NET POWER REQUIREMENT	51.1 KW
INTERNAL COMBUSTION ENGINE SIZE	102.1 KW
ELECTRIC MOTOR SIZE	75.0 KW

ENERGY SAVED=	91630. KW-HOURS OF ELECTRIC
ENERGY SAVED=	28998. LITERS OF DIESEL
ENERGY SAVED=	45949. LITERS OF PROPANE
ENERGY SAVED=	35321. CUBIC M OF NAT. GAS

RESERVOIR SIZE, 1000 CUBIC M	SURFACE AREA HA	SURFACE WIDTH M	PERIMETER OF DIKE M	FILL VOLUME CUBIC M	TURBINE SIZE SQ.M
159.5	5.2	228.8	949.4	24697.9	146.7
148.0	4.9	220.4	915.6	23819.1	156.7
135.6	4.5	211.0	878.1	22842.8	167.4
123.3	4.0	201.2	838.8	21821.1	181.2
111.0	3.6	190.8	797.5	20746.8	194.9
98.6	3.2	179.9	753.9	19611.2	214.1
74.0	2.4	155.8	657.4	17102.7	275.0
49.3	1.6	127.2	543.1	14127.3	349.6
30.8	1.0	100.6	436.5	11354.6	405.6
18.5	0.6	77.9	345.8	8895.4	442.8
17.9	0.6	76.6	340.5	8858.8	447.0
12.3	0.4	63.6	288.6	7507.7	850.0
5.9	0.2	44.0	210.3	5470.3	1316.5

le A-2. TURBINE AND RESERVOIR SIZING ANALYSIS
FOR: REGION B AVERAGE

INPUT DATA:

RESERVOIR SIZING ASSUMPTIONS, METER:

TOP WIDTH	2.4	BOTTOM WIDTH	14.6	DEPTH	3.0
LIFT, METER				36.6	
PEAK WATER USE RATE, CM/DAY				1.16	GROSS
MONTH OF PEAK WATER USE RATE				JULY	
AREA IRRIGATED WITH SIMULATED SYSTEM				40.5	HA
IRRIGATION EFFICIENCY, DECIMAL				0.700	

MONTHLY VALUES

	JAN	FEBR	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
WIND POWER KW/SQ M	.326	.311	.430	.481	.381	.283	.219	.219	.244	.281	.370	.293
LAKE EVAP., CM/MON	3.6	4.1	6.3	9.4	13.0	15.4	17.2	15.8	11.8	8.6	5.2	3.8
RAINFALL, CM/MON	1.2	1.5	2.8	5.3	8.7	10.3	6.7	5.9	5.2	2.6	1.8	1.4
IRR. GROSS, CM/MON	0.0	0.0	0.0	0.3	2.3	5.6	22.1	22.1	11.9	0.0	0.0	0.0

RESULTS:

NET POWER REQUIREMENT	19.5 KW
INTERNAL COMBUSTION ENGINE SIZE	39.0 KW
ELECTRIC MOTOR SIZE	28.6 KW

ENERGY SAVED=	37945. KW-HOURS OF ELECTRIC
ENERGY SAVED=	12009. LITERS OF DIESEL
ENERGY SAVED=	19028. LITERS OF PROPANE
ENERGY SAVED=	14627. CUBIC M OF NAT. GAS

RESERVOIR SIZE, 1000 CUBIC M	SURFACE AREA HA	SURFACE WIDTH M	PERIMETER OF DIKE M	FILL VOLUME CUBIC M	TURBINE SIZE SQ.M
195.1	6.4	253.1	1046.4	27221.5	70.5
184.9	6.1	246.4	1019.7	26525.7	79.1
172.6	5.7	238.0	986.2	25656.4	92.2
148.0	4.9	220.4	915.6	23819.1	122.0
123.3	4.0	201.2	838.8	21821.1	151.4
98.6	3.2	179.9	753.9	19611.2	181.1
74.0	2.4	155.8	657.4	17102.7	223.2
49.3	1.6	127.2	543.1	14127.3	269.7
24.7	0.8	90.0	394.0	10249.6	316.4
20.2	0.7	81.4	359.7	9357.8	324.9
12.3	0.4	63.6	288.6	7507.7	460.3
6.2	0.2	45.0	214.1	5568.8	566.6
4.7	0.2	39.3	191.2	4973.8	591.9

Table A-3. TURBINE AND RESERVOIR SIZING ANALYSIS
FOR: REGION C AVERAGE

INPUT DATA:

RESERVOIR SIZING ASSUMPTIONS, METER:

TOP WIDTH	2.4	BOTTOM WIDTH	14.6	DEPTH	3.0
LIFT, METER				76.2	
PEAK WATER USE RATE, CM/DAY				1.27	GROSS
MONTH OF PEAK WATER USE RATE				AUG	
AREA IRRIGATED WITH SIMULATED SYSTEM				32.4	HA
IRRIGATION EFFICIENCY, DECIMAL				0.700	

MONTHLY VALUES

	JAN	FEBR	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
WIND POWER KW/SQ M	.178	.230	.329	.319	.256	.260	.154	.117	.121	.131	.147	.153
LAKE EVAP., CM/MON	7.4	8.3	11.7	14.3	18.5	21.2	22.2	20.9	17.1	13.7	9.4	7.8
RAINFALL, CM/MON	1.7	1.3	1.6	3.5	8.0	5.9	5.9	5.6	4.8	4.5	1.4	1.7
IRR. GROSS, CM/MON	0.0	0.0	4.8	10.9	1.3	2.8	6.3	13.7	16.3	1.0	2.3	0.0

RESULTS:

NET POWER REQUIREMENT	35.5 KW
INTERNAL COMBUSTION ENGINE SIZE	71.1 KW
ELECTRIC MOTOR SIZE	52.2 KW

ENERGY SAVED=	58493. KW-HOURS OF ELECTRIC
ENERGY SAVED=	18511. LITERS OF DIESEL
ENERGY SAVED=	29332. LITERS OF PROPANE
ENERGY SAVED=	22548. CUBIC M OF NAT. GAS

RESERVOIR SIZE, 1000 CUBIC M	SURFACE AREA HA	SURFACE WIDTH M	PERIMETER OF DIKE M	FILL VOLUME CUBIC M	TURBINE SIZE SQ.M
92.7	3.0	174.4	731.8	19036.5	182.6
88.8	2.9	170.7	716.9	18650.3	198.0
86.3	2.8	168.3	707.4	18401.9	209.1
80.1	2.6	162.2	682.9	17764.8	233.4
74.0	2.4	155.8	657.4	17102.7	259.5
61.6	2.0	142.2	603.1	15690.0	323.8
43.2	1.4	119.0	510.2	13272.2	456.9
30.8	1.0	100.6	436.5	11354.6	545.5
18.5	0.6	77.9	345.8	8995.4	634.2
12.3	0.4	63.6	288.6	7507.7	680.5
10.0	0.3	57.4	263.6	6856.4	697.1
6.2	0.2	45.0	214.1	5568.8	1559.9
4.1	0.1	36.7	181.0	4709.9	2019.5

 Table A-4. TURBINE AND RESERVOIR SIZING ANALYSIS
 FOR: REGION D AVERAGE

INPUT DATA:

RESERVOIR SIZING ASSUMPTIONS, METER:

TOP WIDTH	2.4	BOTTOM WIDTH	14.6	DEPTH	3.0
LIFT, METER			96.0		
PEAK WATER USE RATE, CM/DAY			1.45	GROSS	
MONTH OF PEAK WATER USE RATE			JULY		
AREA IRRIGATED WITH SIMULATED SYSTEM			40.5	HA	
IRRIGATION EFFICIENCY, DECIMAL			0.700		

MONTHLY VALUES

	JAN	FEBR	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
WIND POWER KW/SQ M	.178	.230	.329	.319	.256	.260	.154	.117	.121	.131	.147	.153
LAKE EVAP., CM/MON	9.8	10.4	13.8	16.9	20.0	22.7	24.4	23.1	19.5	16.3	11.6	9.5
RAINFALL, CM/MON	3.8	3.9	3.2	1.4	0.4	0.2	0.5	1.0	0.7	1.1	1.8	4.3
IRR. GROSS, CM/MON	1.8	4.8	14.5	13.2	13.7	19.6	27.4	25.9	14.0	2.5	4.6	0.0

RESULTS:

NET POWER REQUIREMENT	64.0 KW
INTERNAL COMBUSTION ENGINE SIZE	127.9 KW
ELECTRIC MOTOR SIZE	94.0 KW

ENERGY SAVED= 220080. KW-HOURS OF ELECTRIC
 ENERGY SAVED= 69649. LITERS OF DIESEL
 ENERGY SAVED= 110361. LITERS OF PROPANE
 ENERGY SAVED= 84837. CUBIC M OF NAT. GAS

RESERVOIR SIZE, 1000 CUBIC M	SURFACE AREA HA	SURFACE WIDTH M	PERIMETER OF DIKE M	FILL VOLUME CUBIC M	TURBINE SIZE SQ.M
223.6	7.3	270.9	1117.8	29079.0	700.7
197.3	6.5	254.5	1052.0	27366.5	769.3
172.6	5.7	238.0	986.2	25656.4	833.5
148.0	4.9	220.4	915.8	23810.1	838.1
111.0	3.6	190.8	797.5	20746.9	1113.1
74.0	2.4	155.8	657.4	17102.7	1319.5
49.3	1.6	127.2	543.1	14127.3	1499.9
25.1	0.8	90.7	396.9	10324.8	1676.3
24.7	0.8	90.0	394.0	10249.6	1698.8
5.9	0.2	43.9	209.7	5456.0	2761.8

Table A-5. TURBINE AND RESERVOIR SIZING ANALYSIS
FOR: REGION E AVERAGE

INPUT DATA:

RESERVOIR SIZING ASSUMPTIONS, METER:

TOP WIDTH 2.4 BOTTOM WIDTH 14.6 DEPTH 3.0
LIFT, METER 85.3
PEAK WATER USE RATE, CM/DAY 1.09 GROSS
MONTH OF PEAK WATER USE RATE JUNE
AREA IRRIGATED WITH SIMULATED SYSTEM 52.6 HA
IRRIGATION EFFICIENCY, DECIMAL 0.700

MONTHLY VALUES

	JAN	FEBR	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
WIND POWER KW/SQ M	.254	.306	.337	.365	.323	.297	.274	.233	.196	.169	.205	.212
LAKE EVAP., CM/MON	2.4	3.8	6.3	8.8	10.0	12.2	14.4	13.2	9.7	7.3	4.9	3.5
RAINFALL, CM/MON	5.8	5.0	4.7	4.0	4.4	4.9	1.2	1.2	2.1	3.9	5.5	6.5
IRR. GROSS, CM/MON	0.0	0.0	0.0	6.3	13.0	18.5	17.8	13.2	5.6	0.5	0.0	0.0

RESULTS:

NET POWER REQUIREMENT 55.4 KW
INTERNAL COMBUSTION ENGINE SIZE 110.9 KW
ELECTRIC MOTOR SIZE 81.4 KW

ENERGY SAVED= 134209. KW-HOURS OF ELECTRIC
ENERGY SAVED= 42473. LITERS OF DIESEL
ENERGY SAVED= 67301. LITERS OF PROPANE
ENERGY SAVED= 51735. CUBIC M OF NAT. GAS

RESERVOIR SIZE, 1000 CUBIC M	SURFACE AREA HA	SURFACE WIDTH M	PERIMETER OF DIKE M	FILL VOLUME CUBIC M	TURBINE SIZE SQ.M
209.9	6.9	262.5	1084.1	28201.7	285.2
203.4	6.7	258.4	1067.8	27777.1	293.8
197.3	6.5	254.5	1052.0	27366.5	302.3
172.8	5.7	238.0	986.2	25656.4	335.8
149.0	4.9	220.4	915.6	23819.1	370.2
123.3	4.0	201.2	838.8	21821.1	410.2
98.6	3.2	179.9	753.9	19611.2	450.5
74.0	2.4	155.8	657.4	17102.7	508.1
49.3	1.6	127.2	543.1	14127.3	565.8
24.7	0.8	90.0	394.0	10249.6	623.3
22.8	0.7	86.4	379.8	9880.2	628.2
12.3	0.4	63.6	288.6	7507.7	1003.3
5.7	0.2	43.3	207.5	5398.6	1241.1

ab1 -6. TURBINE AND RESERVOIR SIZING ANALYSIS
FOR: REGION F AVERAGE

INPUT DATA:

RESERVOIR SIZING ASSUMPTIONS, METER:

TOP WIDTH 2.4 BOTTOM WIDTH 14.6 DEPTH 3.0
LIFT, METER 24.4
PEAK WATER USE RATE, CM/DAY 1.02 GROSS
MONTH OF PEAK WATER USE RATE AUG
AREA IRRIGATED WITH SIMULATED SYSTEM 48.6 HA
IRRIGATION EFFICIENCY, DECIMAL 0.700

MONTHLY VALUES

	JAN	FEBR	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
WIND POWER KW/SQ M	.255	.299	.331	.320	.187	.120	.073	.070	.098	.131	.260	.221
LAKE EVAP., CM/MON	2.9	3.1	5.2	7.2	9.8	11.4	12.5	11.1	8.9	7.0	4.2	3.0
RAINFALL, CM/MON	5.2	4.7	7.6	9.4	10.3	11.3	8.3	7.8	7.9	7.3	5.9	5.1
IRR. GROSS, CM/MON	0.0	0.0	0.0	0.0	0.0	6.1	9.1	12.2	3.0	0.0	0.0	0.0

RESULTS:

NET POWER REQUIREMENT 13.6 KW
INTERNAL COMBUSTION ENGINE SIZE 27.3 KW
ELECTRIC MOTOR SIZE 20.0 KW

ENERGY SAVED= 14398. KW-HOURS OF ELECTRIC
ENERGY SAVED= 4557. LITERS OF DIESEL
ENERGY SAVED= 7220. LITERS OF PROPANE
ENERGY SAVED= 5550. CUBIC M OF NAT. GAS

RESERVOIR SIZE, 1000 CUBIC M	SURFACE AREA HA	SURFACE WIDTH M	PERIMETER OF DIKE M	FILL VOLUME CUBIC M	TURBINE SIZE SQ.M
129.2	4.2	206.0	857.9	22319.0	37.5
117.1	3.8	196.1	818.4	21291.1	57.2
104.8	3.4	185.5	776.0	20187.4	77.3
86.3	2.8	168.3	707.4	18401.9	112.2
74.0	2.4	155.8	657.4	17102.7	139.9
61.6	2.0	142.2	603.1	15690.0	179.8
49.3	1.6	127.2	543.1	14127.3	230.4
37.0	1.2	110.2	474.9	12353.6	279.6
24.7	0.8	90.0	394.0	10249.6	329.5
18.5	0.6	77.9	345.8	8995.4	354.5
13.4	0.4	66.2	299.1	7779.7	388.7
12.3	0.4	63.6	288.6	7507.7	500.0
4.9	0.2	40.2	195.1	5074.7	1296.2

Table A-7. TURBINE AND RESERVOIR SIZING ANALYSIS
FOR: REGION G AVERAGE

INPUT DATA:

RESERVOIR SIZING ASSUMPTIONS, METER:

TOP WIDTH	2.4	BOTTOM WIDTH	14.6	DEPTH	3.0
LIFT, METER				38.1	
PEAK WATER USE RATE, CM/DAY				1.16	GROSS
MONTH OF PEAK WATER USE RATE				MAY	
AREA IRRIGATED WITH SIMULATED SYSTEM				36.4	HA
IRRIGATION EFFICIENCY, DECIMAL				0.700	

MONTHLY VALUES

	JAN	FEBR	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
WIND POWER KW/SQ M	.088	.110	.118	.101	.064	.047	.038	.034	.053	.063	.069	.072
LAKE EVAP., CM/MON	6.6	6.6	8.4	9.8	11.7	12.4	13.0	12.2	10.7	9.2	7.2	6.5
RAINFALL, CM/MON	6.2	7.9	9.3	8.5	7.8	15.1	19.7	17.9	16.6	10.7	4.9	6.9
IRR. GROSS, CM/MON	0.0	0.0	11.7	11.7	13.5	3.8	4.8	1.0	12.4	11.7	0.0	0.0

RESULTS:

NET POWER REQUIREMENT	18.3 KW
INTERNAL COMBUSTION ENGINE SIZE	36.5 KW
ELECTRIC MOTOR SIZE	26.8 KW

ENERGY SAVED=	39089. KW-HOURS OF ELECTRIC
ENERGY SAVED=	12371. LITERS OF DIESEL
ENERGY SAVED=	19602. LITERS OF PROPANE
ENERGY SAVED=	15068. CUBIC M OF NAT. GAS

RESERVOIR SIZE, 1000 CUBIC M	SURFACE AREA HA	SURFACE WIDTH M	PERIMETER OF DIKE M	FILL VOLUME CUBIC M	TURBINE SIZE SQ.M
97.6	3.2	179.0	750.2	19514.7	278.5
92.5	3.0	174.2	731.0	19016.6	288.3
86.3	2.8	168.3	707.4	18401.9	300.1
80.1	2.6	162.2	682.9	17764.8	312.2
74.0	2.4	155.8	657.4	17102.7	324.1
61.6	2.0	142.2	603.1	15690.0	352.1
49.3	1.6	127.2	543.1	14127.3	383.0
37.0	1.2	110.2	474.9	12353.6	416.3
24.7	0.8	90.0	394.0	10249.6	507.4
12.3	0.4	63.6	288.6	7507.7	810.7
11.1	0.4	60.3	275.2	7159.5	821.2
6.2	0.2	45.0	214.1	5568.8	1536.8
4.2	0.1	37.2	183.1	4764.1	1898.7

Figure A-1. Turbine size versus reservoir size - Region A.

Figure A-2. Turbine size versus reservoir size - Region B.

Figure A-3. Turbine size versus reservoir size - Region C.

Figure A-4. Turbine size versus reservoir size - Region D.

Figure A-5. Turbine size versus reservoir size - Region E.

Figure A-6. Turbine size versus reservoir size - Region F.

Figure A-7. Turbine size versus reservoir size - Region G.

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APPENDIX B

Breakeven Investment Values, Wind Assist
Without Sale of Surplus Electricity

Figure B-1. Breakeven investment value (1980 dollars) by turbine size for diesel by energy price scenario, wind assist without sale of surplus electricity, Region A.

Figure B-2. Breakeven investment value (1980 dollars) by turbine size for LPG by energy price scenario, wind assist without sale of surplus electricity, Region A.

Figure B-3. Breakeven investment value (1980 dollars) by turbine size for natural gas by energy price scenario, wind assist without sale of surplus electricity, Region A.

Figure B-4. Breakeven investment value (1980 dollars) by turbine size for diesel by energy price scenario, wind assist without sale of surplus electricity, Region B.

Figure B-5. Breakeven investment value (1980 dollars) by turbine size for natural gas by energy price scenario, wind assist without sale of surplus electricity, Region D.

APPENDIX C

Breakeven Investment Values, Wind Assist With Sale of Surplus Electricity

Figure C-1. Breakeven investment value (1980 dollars) by turbine size for electricity by energy price scenario, wind assist with sale of surplus electricity, Region A.

Figure C-2. Breakeven investment value (1980 dollars) by turbine size for electricity by energy price scenario, wind assist with sale of surplus electricity, Region B.

Figure C-3. Breakeven investment value (1980 dollars) by turbine size for electricity by energy price scenario, wind assist with sale of surplus electricity, Region C.

Figure C-4. Breakeven investment value (1980 dollars) by turbine size for electricity by energy price scenario, wind assist with sale of surplus electricity, Region D.

Figure C-5. Breakeven investment value (1980 dollars) by turbine size for electricity by energy price scenario, wind assist with sale of surplus electricity, Region E.

Figure C-6. Breakeven investment value (1980 dollars) by turbine size for electricity by energy price scenario, wind assist with sale of surplus electricity, Region F.

Figure C-7. Breakeven investment value (1980 dollars) by turbine size for electricity by energy price scenario, wind assist with sale of surplus electricity, Region G.

APPENDIX D

Breakeven Investment Values, Stand Alone System

Figure D-1. Breakeven investment value (1980 dollars) by turbine size and energy source, by energy price scenario, stand alone system, Region A.

Figure D-2. Breakeven investment value (1980 dollars) by turbine size and energy source, by energy price scenario, stand alone system, Region B.

Figure D-3. Breakeven investment value (1980 dollars) by turbine size and energy source, by energy price scenario, stand alone system, Region C.

Figure D-4. Breakeven investment value (1980 dollars) by turbine size and energy source, by energy price scenario, stand alone system, Region D.

Figure D-5. Breakeven investment value (1980 dollars) by turbine size for electricity, by energy price scenario, stand alone system, Region E.

Figure D-6. Breakeven investment value (1980 dollars) by turbine size and energy source, by energy price scenario, stand alone system, Region F.

Figure D-7. Breakeven investment value (1980 dollars) by turbine size and energy source, by energy price scenario, stand alone system, Region G.